Converted wave prestack migration in the presence of topography: synthetic cases

Saul Guevara and Gary Margrave

ABSTRACT

Converted waves can provide valuable structural and stratigraphic information, which requires suitable processing methods such as prestack migration. Rough topography, present at many places of interest, can reduce the quality of the resulting images. A method of Kirchhoff prestack migration for converted waves in the presence of topography is presented here. A prestack depth migration code for shot gather data was used. Two different synthetic datasets, containing shot gathers with topography over different subsurface structures, were created using an elastic 2D finite-difference method. An eikonal ray-tracing code was used to create the time tables for P and S waves, and the resulting images are presented in time and depth versions. Depth images resemble accurately the geologic model in depth. However, they also appear to have a number of artifacts, mostly related to other wave modes present in the record, and also related to the migration process.

Future work includes more extended applications of these methods, and increasing the accuracy by taking into account issues such as anisotropy and true amplitude.

INTRODUCTION

It has been shown that converted waves (P to S) have rich information content; however, improving the processing methods is required to take advantage of that information. The traditional approach assumes a common conversion point (or CCP, Tessmer and Behle, 1988; Stewart et al. 2002), usually estimated assuming a flat layer ("layercake") model, and successful results have been obtained with it. However, its accuracy diminishes if the geology moves away of the flat layer model.

Prestack depth migration (PSDM) appears as an optimal tool in cases such as for complex areas, and does not assume such a simple model, consequently being a more appropriate approach for converted waves. Since many places of interest are located in rough terrain, taking into account topography can also be critical. This work takes into account these issues.

The method developed in this case, and tests of it with synthetic data, are presented and some conclusions and possible future work are considered.

METHODOLOGY

The Kirchhoff migration algorithm, applied to P waves in the conventional seismic method, but extended to P-S waves here, was the starting point for this application. Synthetic 2D elastic data were used for testing. Two simple geological models including topography were used to create these synthetic data. One shot was used and analyzed in each case.

We modified a conventional Kirchhoff prestack time migration program to include depth migration for converted waves with variable topography. This is a shot gather type migration. Ray tracing was carried out using the Eikonal code created by Chad Hogan at CREWES, following Sethian and Popovici (1999).

Two geological velocity models for P and S waves, and including topography, were created. Wave propagation was modeled using an elastic 2D finite difference code based on the method proposed by Hayashi et al. (2001). The horizontal components of these data sets were used as an input to the P-S migration procedure. It is assumed that converted waves are mostly included in this component.

The input data for migration includes the shot gather, horizontal and vertical coordinates of sources and receivers, and the P and S wave velocity models used for modeling. A number of migration parameters such as migration aperture or the target to be migrated can be also selected. The output consists of two versions of migrated data: time and depth.

RESULTS

The input and output data at the various stages and the results obtained after migration are presented in the following sections.

Model 1:

Model 1 is illustrated in Figures 1 and 2. The geometry and rock properties are illustrated in Figure 1. The same properties are used in model 2. The source location is illustrated by a star. The first layer is air, required in order to simulate topography, and the receivers are located at the first interface. Figure 2 is the model used for the migration program.

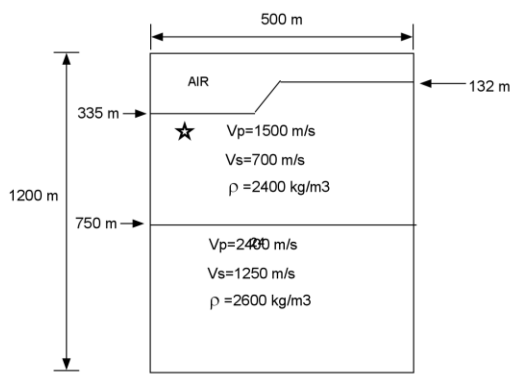


FIG. 1. Geological model1. The receivers are in the surface below “Air” and the source is shown by a star.

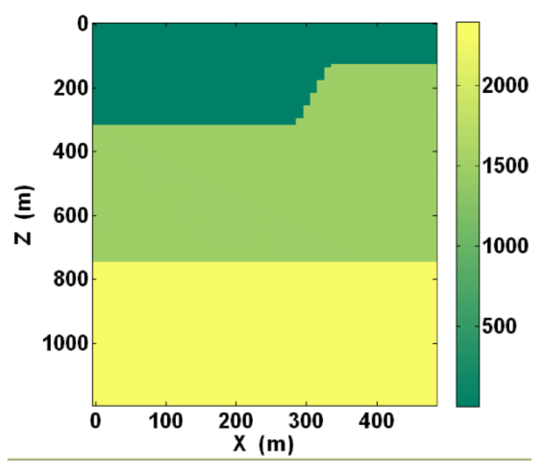


FIG.2. Velocity model 1. P wave used in migration.

FIG. 3 illustrates the horizontal component of the synthetic data of Model 1. The main events are PS waves and SS waves which are shown with numbers. Figure 4 illustrates the ray tracing time results for the P-wave and the S wave used in the migration algorithm.

Figures 5 and 6 show the migrated data set resulting from our PSDM, Figure 5 in time and Figure 6 in depth. The two noticeable events are the same shown in Figure 3. Notice that event 1, the PS wave, is located at the depth corresponding to the interface, as shown in Figure 2. Some artifacts are also observed.

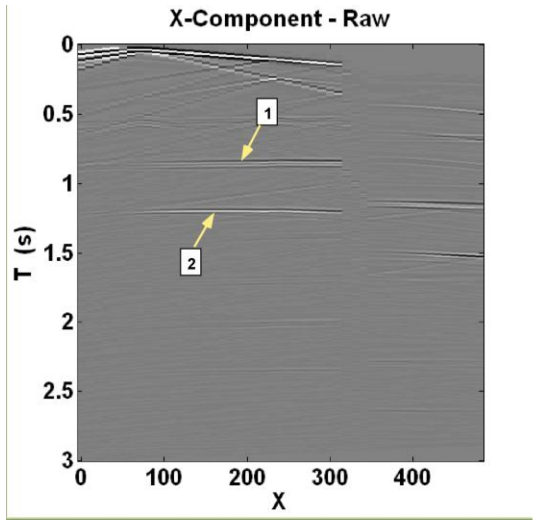


FIG.3. Synthetic shot gather for model 1, horizontal component. Number 1 is PS wave and Number 2 is SS wave.

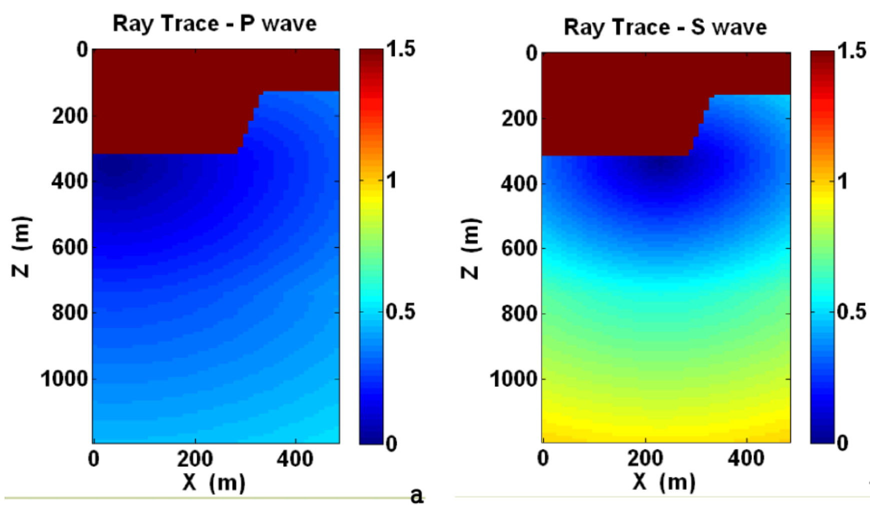


FIG.4.Times obtained with ray tracing (a) P-wave (source) and (b) S-wave (for a receiver).

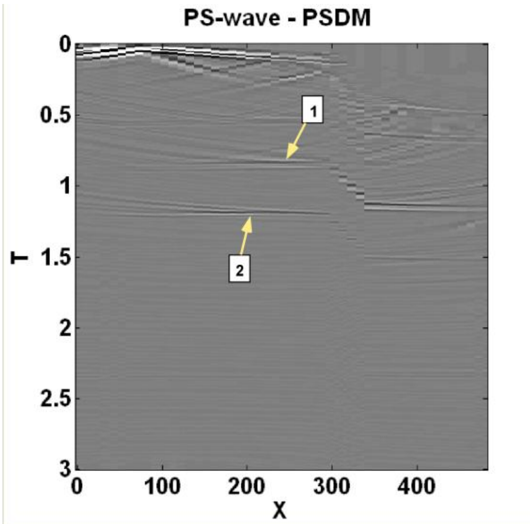


FIG.5. Shot gather of converted wave PSDM in time.

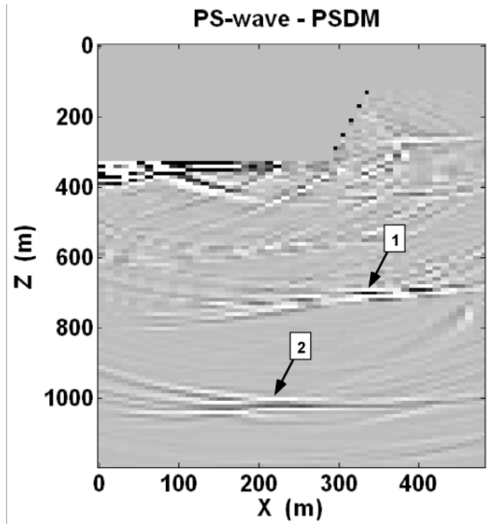


FIG.6. Converted wave PSDM in depth. The arrow shows the main events. No. 1 corresponds to the PS.mode and No. 2 to the SS mode.

Model 2

Model 2 has a more complex geology and topography. Figure 7 is the velocity model with the three layers analogous to the layers of Model 1. The geologic properties are the same as in Figure 1, the receivers are on the surface of the first interface and the source is approximately at the same location of Model 1.

Figure 8 shows the two components of this shot, where 8a is the vertical and 8b is the horizontal. Notice that similar events can be identified in both components, that is to say, it is more difficult to separate P and S modes than in Model 1. Figure 8b shows two events identified with No. 1 and No 2 PS.

Figure 9 shows the migrated shot in depth. Many events can be observed, but it is difficult to relate them with the geologic model (compare with Figure 7). An interpretation is tried, as shown by the number 1, which corresponds to the depth of a geologic interface, and the number 2, which does not correspond to anything in the model. Consequently, event 1 would be the PS wave and event 2 a PP wave.

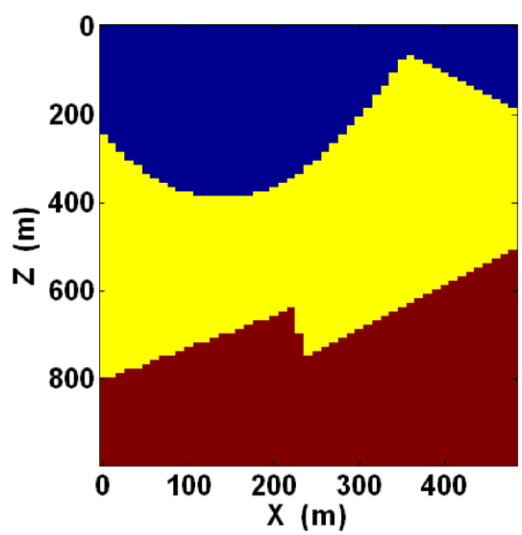
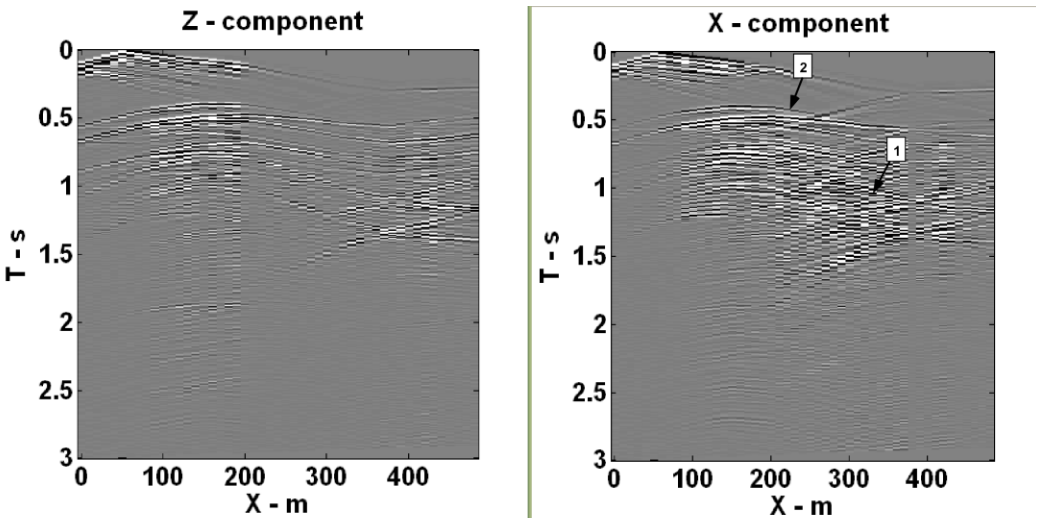


FIG.7. Model 2 Velocity of P wave.



a b

FIG.8. Shot gathers of the two components of Model 2. (a) the vertical component and (b) the horizontal component. Probably event 1 is the PS wave and event 2 is the PP wave.

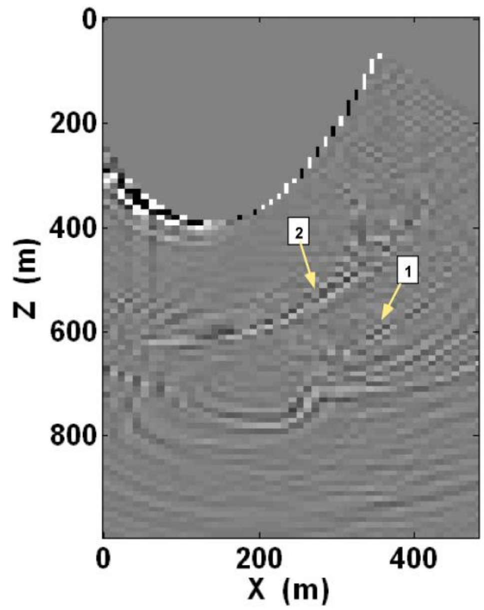


FIG.9. Converted wave PSDM of the horizontal component presented in depth event. No. 1 can correspond to the PS mode and event No. 2 to the PP mode.

FUTURE WORK

It would be useful to try a more extended test of the current method using a bigger synthetic data set. It can be related to a real seismic survey. A real multicomponent data set can also be considered.

Some details of the method need to be considered, such as the amplitude correction in the migration step for converted waves. A more accurate model that takes into account anisotropy can also be taken into account, since this is a property that would be also present in many cases of real data.

True amplitude and gathers in the angle domain are important issues related to methods such as AVO, which can provide important information.

CONCLUSION

PSDM for converted wave in rough terrain using the Kirchhoff approach shows promising results applicable to structural and stratigraphic problems. Future research can take into account advanced issues, which can be focused in solutions applicable to real cases, since this method has potential for developments applied to the industry.

REFERENCES:

Hayashi, K., Burns, D. and Töksoz, N, 2001, Discontinuous-Grid Finite-Difference Seismic Modeling Including Surface Topography: Bulletin of the Seismological Society of America, 91, 6, pp. 1750–1764.

Sethian J., and Popovici, M., 1999, 3-D traveltime computation using the fast marching method: Geophysics 64 no 2 pp 516-523.

Stewart Robert R. Stewart, R.R., Gaiser, J. E., Brown, R. J. and Lawton, D. C., 2001, Converted wave seismic exploration: methods: Geophysics, 67, No.5, 1348-1363.

Tessmer, G,. and Behle, A, 1988, Common reflection point data-stacking for converted waves: Geophysical Prospecting 36,671-688.